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The Effect of Soil Compaction on Earthworms (*Lumbricidae*) in a Heavy Clay Soil

ULLALENA BOSTRÖM

Department of Ecology and Environmental Research

Abstract. Earthworms were sampled in a long-term field trial on a heavy clay soil with different traffic intensities and N-application rates.

The biomass of all earthworm populations was higher in plots fertilized with 1.5 × the recommended dose of nitrogen compared with plots receiving the recommended dose. Earthworm biomass was lower in treatments trafficked by tractors (high soil compaction) than in treatments in which the implements had been hauled by a winch for 20 years (i.e., low soil compaction). The ratio of juveniles to adults of *A. caliginosa* was lower in trafficked than in untrafficked treatments. It was not possible to distinguish between the direct and indirect effects of soil compaction. However, a positive correlation between earthworm biomass and grain yield indicated the importance of food supply.

Key words: earthworms, heavy clay, N-fertilization, soil compaction.

INTRODUCTION

Modern farming practices rely on the use of large, heavy machinery and on more vehicular traffic on the fields than in the past. High-powered tractors make it possible to cultivate even when the soil is wet and the risk for compaction damage is high. Water content affects soil compressibility, and machinery traffic, especially on heavy soils of too high moisture content, compacts the soil and causes structural damage.

Earthworms affect soil structure through their burrowing and casting activities which redistribute the mineral soil and organic matter. Worms are especially noted for their ability to increase water infiltration rate, but in addition, they can also increase soil porosity (Stockdill & Cossens, 1966; van de Westeringh, 1972). More water-stable aggregates are formed in soils containing worms than in worm-free soil (Teotia et al., 1950; van Rhee, 1969).

In polder soils in the Netherlands the activity of inoculated worms increased air permeability within the surface horizon and counteracted soil compaction in the upper few centimeters of the soil in the wheel tracks (Rogaar & Boswinkel, 1978). Earthworm activity is clearly important in ameliorating the soil structure and may counteract the deterioration caused by heavy farm machinery. The aim of this study was to compare the various earthworm populations in a heavy clay soil which had been exposed to different levels of soil compaction for several years.

MATERIALS AND METHODS

Studies on the effects of reducing soil compaction in Sweden have been described by Håkansson et al. (1985). One experimental site with very heavy clay (Stensfält) was subjected to various treatments from 1964 until 1984 and was sampled for earthworms in September 1983. The annual treatments were as follows:

SN. Tractors with *s*tandard (single) rear wheels with the inflation pressure 100–120 kPa. *N*ormal spring sowing time, i.e. sowing was begun as soon as the soil had dried sufficiently.

DN. Tractors with *d*ual rear wheels with the inflation pressure 50–60 kPa. However, ploughing was still done using tractors with the same wheels as in SN. Sowing time as in SN.

WN. A *w*inch was used to haul implements. No machinery traffic except at harvest. Sowing time as in SN.

WE. A winch was used to haul implements as in WN. *E*arly sowing time, i.e. sowing was begun as soon as the hauled implements could be operated satisfactorily.

Harvesting was done with a light-weight combine harvester in all treatments and the grain yields were measured. The straw was annually ploughed under in the autumn. From 1974 until 1982, half of each experimental plot was fertilized with the recommended dose of nitrogen for each crop (in the form

Table 1. *Numbers (m^{-2}) and biomass ($g\ m^{-2}$) of earthworms presented as means ± SE averaged over the main treatments for two nitrogen levels*

N = recommended dose nitrogen. 1.5 N = 1.5× recommended dose

	Numbers		Biomass	
	N	1.5 N	N	1.5 N
A. caliginosa				
Adults	12.8±2.3*	18.4±3.4	6.5±1.1*	9.3±1.6
Juveniles				
All	36.7±10.3 NS	42.7±8.4	6.3±1.9 NS	7.0±1.5
Large	12.8±3.7 NS	14.6±3.1	3.6±1.1 NS	4.1±0.9
Medium-sized	15.0±4.7 NS	14.4±3.1	2.2±0.7 NS	2.1±0.5
Small	8.9±2.2 NS	13.8±3.1	0.6±0.2 NS	0.9±0.2
All earthworm populations	52.2±12.6 NS	62.9±11.2	13.8±2.9*	16.8±2.9

Significance levels: *$p<0.05$. NS=not significant.

of calcium nitrate) while the other half of the plot received 1.5 × the recommended dose. The main crops during the period were spring-sown barley (*Hordeum distichum* L.) and oats (*Avena sativa* L.). The average recommended dose of nitrogen was 67 kg N ha^{-1}. During 1980 the field was left fallow.

Earthworms were sampled with the formalin method (Raw, 1959) immediately after the 1983 harvest. One sample was taken in each experimental plot, avoiding wheel tracks from the harvester. Ten liters of 0.2% formalin was applied twice at 15-min intervals in a 0.5 m^2 frame driven 5 cm down into the soil. The stubble within the frame had been cut to ground level and all litter carefully removed. All worms appearing within 1.5 h were collected and immediately rinsed; thereafter they were kept in water at 5°C for one day. Live worms were identified to species, separated into adults and juveniles, counted and individually weighed. Individuals of *Allolobophora caliginosa* (Sav.) were separated according to weight into groups of small (<100 mg), medium-sized (100–200 mg), and large (>200 mg) juveniles. The numbers of juveniles per adult *A. caliginosa* were then calculated.

An incomplete block design was used for the experiment with SN and WN in six blocks and DN and WE in three blocks. In the analysis of variance (ANOVA) the block-factor and the interactions between blocks and treatments were assumed to occur at random. This assumption of randomness was taken into consideration when estimating the standard errors used to construct confidence intervals and used in the *t*-tests.

RESULTS AND DISCUSSION

No significant interaction ($p>0.05$) was found between soil compaction and nitrogen and, as a consequence, this term was omitted from the ANOVA-model.

The numbers and biomass of adult *A. caliginosa* and the total biomass of all earthworm populations were significantly higher ($p<0.05$) in the plots which received the higher nitrogen dose (Table 1). Grain yields were also higher in these plots (Håkansson, pers. comm.).

Heath (1962) found that the earthworm biomass in a ley was higher in N-fertilized plots than in unfertilized plots during only 1 of 4 years investigated. The nitrogen applied in Heath's study (310 kg N ha^{-1}) was in the form of nitrochalk. In a bluegrass turf, biomass decreased as the dose of nitrate increased (0–250 kg N ha^{-1}) (Potter et al., 1985). They proposed that the main causes for this decrease were the acidity produced by nitrification of ammonium nitrate and the reduction in exchangeable Ca in the acidic soil. Edwards & Lofty (1975) also found a sharp reduction in earthworm numbers at Rothamsted in plots supplied with nitrogen, irrespective of whether the fertilizer applied (0, 48, 96 and 144 kg N ha^{-1}) was ammonium sulfate or sodium nitrate. Gerard & Hay (1979), on the other hand, found about 30% more earthworms in plots with nitrochalk (50 and 100 kg N ha^{-1}) than in plots lacking supplemental nitrogen, and they concluded that different earthworm species were affected differentially. Lofs-Holmin (1983) found no relationship between dose (150–450 kg N ha^{-1}) or

Table 2. *Numbers (m^{-2}) and biomass ($g\ m^{-2}$) of earthworms presented as means ± SE averaged over two nitrogen levels for the main treatments*

S = single rear wheels. D = dual rear wheels. N = normal sowing time. E = early sowing time

Species		Tractor		Winch		Significant differences
		SN	DN	WN	WE	
A. caliginosa						
Adults	Numbers	6.8±1.7	13.0±4.6	25.0±5.3	17.0±0.6	SN*WN
	Biomass	3.9±0.9	7.1±3.0	12.1±2.4	8.6±0.9	SN*WN
Juveniles						
All	Numbers	7.7±1.7	19.3±6.4	69.5±17.4	64.7±6.9	SN***WN, SN**WE, DN*WN
	Biomass	1.5±0.3	3.2±1.1	11.6±3.6	10.8±0.8	SN**WN, SN*WE, DN*WN
Large	Numbers	3.8±0.9	8.0±2.9	22.5±7.9	21.3±1.8	SN**WN
	Biomass	1.1±0.3	2.1±0.8	6.4±2.4	5.9±0.5	SN**WN
Medium-	Numbers	2.2±0.9	4.3±1.5	27.0±7.2	25.7±2.3	SN**WN, SN**WE, DN**WN, DN*WE
sized	Biomass	0.3±0.1	0.7±0.2	3.9±1.0	3.7±0.4	SN**WN, SN**WE, DN**WN, DN*WE
Small	Numbers	1.7±0.5	7.0±2.9	20.0±3.5	17.7±5.2	SN***WN, SN*WE
	Biomass	0.1±0.0	0.4±0.2	1.3±0.3	1.2±0.4	SN***WN, SN**WE, DN**WN
All earthworm	Numbers	15.5±2.6	32.7±8.5	97.5±22.7	86.7±9.7	SN***WN, SN**WE
populations	Biomass	5.5±0.9	10.3±3.4	24.4±6.0	21.7±1.3	SN**WN, SN*WE, DN*WN

Significance levels: * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

type of fertilizer (ammonium sulfate, ammonium nitrate, calcium nitrate) and number of earthworms on a clay soil. On a peat soil, more *Dendrobaena subricunda* (Eisen) were found in plots fertilized with nitrogen (56 kg ha^{-1}) than in unfertilized plots. In contrast, populations of *D. octaedra* (Sav.) were not apparently affected by N-fertilization.

The effect of nitrogen on earthworm populations will vary depending on a number of factors, such as the species present and the type and amount of fertilizer. Soil type and plant nutrient availability, together with weather conditions, affect the above- and below-ground crop production, thereby affecting the supply of earthworm food.

A. caliginosa was the predominant species in all treatments at Stensfält. Numbers and biomass of all groups of earthworms were significantly higher in WN than in SN (Table 2). The WN- and SN-treatments occurred in twice as many blocks as did the others so, on the basis of the experimental design, it was easier to detect statistically significant differences between these two treatments than between the others. Numbers and biomass of all groups but adults and large juveniles of *A. caliginosa* were also significantly higher in WE than in SN. The biomasses of small and medium-sized juveniles of *A. caliginosa* were significantly higher in WN than in DN. Sowing time did not significantly influence the earthworm population.

Numbers and biomass of earthworms were about twice as high in DN as in SN, but the differences were not statistically significant ($p>0.05$). No differences between treatments were found in individual worm weights derived from Table 2.

The numbers of juveniles per adult were lower in trafficked (SN and DN) than in untrafficked plots (Fig. 1). The differences were statistically significant for the groups of "all" and "medium-sized" *A. caliginosa* juveniles.

Evans & Guild (1948) found that the rate of cocoon-production varies with the quality of the food supply. They had earlier demonstrated that unmated *Allolobophora* spp. do not produce cocoons (Evans & Guild, 1947).

Small juveniles of *A. caliginosa* are usually found in the upper 0–5 cm of the soil, while larger juveniles and adults usually are found deeper down (Rundgren, 1975). Hence small juveniles are more exposed to the pressure and crushing effects of the tractor wheels. Most traffic in the plots occurred during spring. It is not possible to determine the age of earthworms and Rundgren (1977) emphasized that juveniles exposed to an adverse soil climate can remain the same size for several months after emergence. Thus it is meaningless to try and char-

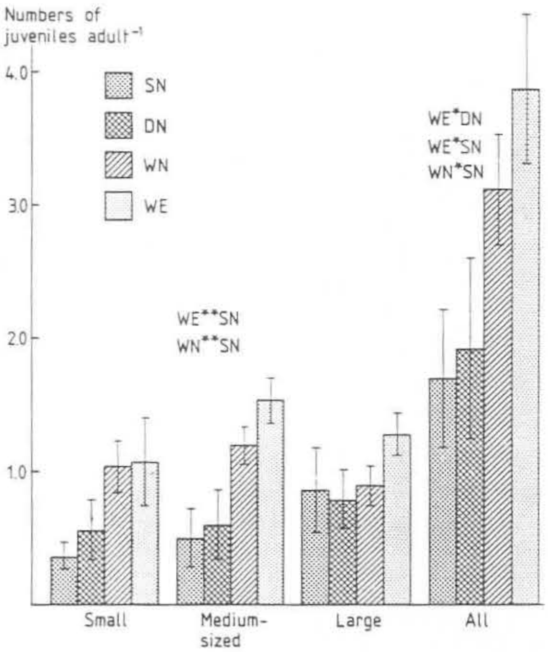

Fig. 1. Numbers of juveniles per adult *A. caliginosa* for different weight-classes in plots with various degrees of soil compaction. S = tractors with single rear wheels. D = tractors with dual rear wheels. W = implements hauled by a winch. N = normal sowing time. E ≡ early sowing time. Levels of significance: $^*p<0.05$, $^{**}p<0.01$. Vertical bars indicate standard error.

acterize the changes in the population structure during the year, based on a single sample occasion. The adults which produced the juveniles found in this sampling could have been fewer than or more numerous than the sampled adults. However, if adult mortality had been higher in the trafficked plots than in the untrafficked plots, the ratios of juveniles to adults should have increased in the former. According to Fig. 1, however, the ratios were actually decreased i.e. more juveniles were found per adult *A. caliginosa* in untrafficked than in trafficked plots. This situation could have arisen if one or more of the following conditions were met: (1) juveniles were more exposed than adults to mechanical damage by the tractor wheels; (2) the food supply in trafficked plots was smaller than that in untrafficked plots; (3) the lower abundance of worms in trafficked plots left more adults unmated.

Håkansson et al. (1985) reported decreased crop yields in trafficked plots and hypothized that the effects of oxygen deficiency, directly or indirectly, could have caused this decrease. Traffic reduced water infiltration, decreased the volume of large pores, and decreased air permeability, thereby causing the oxygen deficiency. Deterioration of the soil structure surely has a direct negative influence on the population. Dexter (1978) found that the degree of tunneling by worms in a loam soil was independent of soil strength over the range of 0.3–3 MPa. However, at least during dry periods, the heavy clay at Stensfält develops a soil strength considerably higher than 3 MPa. Consequently, the compacted soil may have impaired earthworm locomotion, resulting in decreased availability of food and fewer mated adults.

Earthworm biomass fluctuates between years and during 1983 (the year of sampling) it was probably too low in all treatments to significantly affect the soil structure.

A positive correlation was found between earthworm numbers and biomass and the grain yields in the individual plots 1982 ($p<0.001$, $n=36$) and 1983 ($p<0.001$, $n=18$). A high grain yield is probably also associated with more straw, more crop residues and more roots, all of which serve as food for earthworms when ploughed under. Hence it was impossible to distinguish between the direct effects of soil compaction and its indirect effects such as changes in food supply.

The influence of soil compaction on earthworms has been investigated by Aritajat et al. (1977) in a one-year trial. Studying a silt-loam grassland, they found significantly reduced worm numbers in treated plots (compacted by driving over the area ten times with a tractor) compared with untreated plots. However, no differences in numbers or body weights of earthworms were recorded between uncompacted and compacted plots on a clay grassland. Heavy trampling by livestock in pasture entrances and vehicular compaction on a human path through pasture also reduced earthworm density and biomass (Piearce, 1984).

This study clearly shows that earthworm numbers and biomass were lower in treatments trafficked by tractors. Worm populations were slightly higher in plots trafficked by tractors with dual rear wheels than in plots trafficked by tractors with single rear wheels. The importance of increased food supply was indicated in two ways: by the increased earthworm biomass found in plots fertilized with the higher nitrogen dose and by the positive correlation existing between earthworm biomass and grain yield. The decrease of earthworm

populations in trafficked plots was proportionately greater than the decrease in grain yields. This indicates that the traffic and resulting soil compaction also had a direct impact on the abundance and biomass of earthworms.

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Ullalena Boström
Swedish Univ. Agric. Sci.
Department of Ecology
and Environmental Research
P.O. Box 7072
S-750 07 UPPSALA, Sweden